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THESIS

Visual and Proprioceptive Inputs on Spatial Orientation
in the Pitch Dimension

by

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September 1989

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The purpose of this study was to determine the relative influence of visual and proprioceptive inputs on judgments of body orientation by assessing the effects of initial starting body position (SP), visual field variation (VFV), and trial sequence (T). Subjects, secured to a 360 degree rotating bed surrounded by a tilting box, attempted to orient themselves to vertical and horizontal body positions under light and dark conditions. SP was either ±15 degrees from vertical or horizontal. When subjects placed themselves horizontal, they were affected by VFV, and had a head-high mean deviation of +1.45 degrees from horizontal. When subjects placed themselves vertical, they were affected by SP and T, and had a head-back mean deviation of -2.94 degrees from vertical.

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Visual and Proprioceptive Inputs on Spatial Orientation in the Pitch Dimension

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ABSTRACT

The purpose of this study was to determine the relative influence of visual and proprioceptive inputs on judgments of body orientation by assessing the effects of initial starting body position (SP), visual field variation (VFV), and trial sequence (T). Subjects, secured to a 360 degree rotating bed surrounded by a tilting box, attempted to orient themselves to vertical and horizontal body positions under light and dark conditions. SP was either ±15 degrees from vertical or horizontal. When subjects placed themselves horizontal, they were affected by VFV, and had a head-high mean deviation of +1.45 degrees from horizontal. When subjects placed themselves vertical, they were affected by SP and T, and had a head-back mean deviation of -2.94 degrees from vertical.

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I. INTRODUCTION

A. OVERVIEW

Human spatial orientation is determined by visual (retinal and extraretinal) and non-visual (proprioceptive, vestibular, and kinesthetic) inputs. These inputs enable man to orient his body in a normal (1-G) terrestrial environment without becoming disoriented. By use of these various inputs, man is able to locomote normally in that environment. Technology has pushed man to the limits of these inputs. Just the act of driving a car fast and having the countryside pass quickly before them causes some people to feel dizzy. In a more complex arena, pilots flying low levels at high speeds, close to mountains, over hilly terrain, or catapulting off a carrier can become quickly disoriented. This problem can only intensify as man is required to function in more hi-tech, non-terrestrial environments.

A long term goal of interplanetary exploration has been established by national policies since 1961, which President Kennedy called for scientists to develop the technology that would extend our presence into space. Our current National Space Policy, approved by President Reagan in January 1988, and reaffirmed by President Bush in July 1989, provides the United States with a national commitment to the exploration and use of space in the support of our national well-being. Two of the principle goals called for in this policy are to expand human presence in low earth orbit and to extend manned activities beyond earth orbit into the solar system. In the interest of national security we must take this commitment seriously. Since 1964 the

USSR has had a nearly continuous manned presence in space in support of their national goals. American astronauts have reported the ability to view the earth more clearly and in more detail than has ever been attained by photographs.

To accomplish the mission of extending man's presence to low earth orbit and beyond, we must first understand the mechanisms that make man so well suited to the normal terrestrial environment, and specify what accommodations for him will be needed to extend his presence in space. The exploration of space challenges man's abilities to orient himself and other objects spatially because of exposure to the various G levels inherent in space travel that alter visual and nonvisual input mechanisms.

First, we must adapt to an environment with a gravitational force normally less than that of the earth. If we establish outposts on the moon we will have to adapt to a gravitational force one sixth of that on earth. If we wish to establish orbiting space stations we will have to adapt to a near-zero (micro) gravitational force. Both flight and spaceflight create environments that are radically different from the terrestrial one in which man developed. Medical evidence reveals that, in each of these environments, long term exposure results in physiological changes, which tend to adapt the body to that environment. Upon returning to earth, the body must readapt to its original environment. The aftereffects of space travel, which vary both in severity and duration, depend on the biological system involved and the length of exposure to the non-terrestrial environment.

As technology progresses, the interaction between the human and the machine remains critical, and it is important that the human continue to

operate at peak efficiency to avoid errors in judgement and manipulation of controls. Examples of critical functions that must be accomplished either on earth or in low earth orbit include: catapulting off a carrier, maneuvering an aircraft in a tactical environment, docking of a spacecraft, extra vehicular activity, and landing after reentry. Some activities necessary to perform these functions involve simple reflexes, while other activities are complex, and involve interactions from proprioceptive and exteroceptive systems.

B. LITERATURE REVIEW

1. The Proprioceptive and Exteroceptive Systems

The act of reaching for an object or performing various physical tasks are normally defined by our 1-G environment. Our motions are affected by several mechanisms that involve (1) kinaestheic and proprioceptive receptors, (2) vestibular, and (3) retinal and extraretinal mechanisms.

In 1906 Sherrington proposed the terms *exteroceptive* and *proprioceptive* fields. Exteroceptive refers to sensory systems that respond to stimulation from the environment, or outside an organism. Proprioceptive refers to the sensory systems that respond to stimulation from within an organism. [Ref. 1:pp. 175-176]

The proprioceptive system provides the central nervous system (CNS) with continuous information about changes in body positions that result from motor activity. Proprioceptors are found in muscles, tendons, and joints, and are therefore well suited to respond to mechanical forces. Their primary function is the control of spatial orientation, posture, and locomotion. Sherrington first conceived of what is now called *proprioceptive*

feedback to indicate that this control is cyclic in nature. Two groups of proprioceptors are: (1) muscle and (2) joint and cutaneous. [Ref. 1:pp. 176-177]

Muscle proprioceptors are found in striated muscle, and are basically stretch receptors that register relative lengths and tensions in muscles.

Joint and cutaneous proprioceptors vary in size, shape, and complexity. They serve as both proprioceptors and exteroceptors, and are sensitive to pressure or changes in pressure, relative positions of body joints, and differential pressures associated with various body pressures relative to hard surfaces. Cutaneous proprioceptors provide the CNS with information about the changes in distributions of pressure that result from changes in body posture and orientation. [Ref. 1:pp. 180-181]

Exteroceptors may be "contact" receptors, like those found in the skin and the tongue, or "distant" receptors, like those found in the eyes and ears [Ref. 1:pp. 182-185].

Vestibular receptors are found in the nonauditory part of the inner ear. The vestibular receptors determine angular & linear acceleration (head-movement), and provide a working surface for exteroceptor functioning. [Ref. 1:pp. 182-185] The vestibular system maintains equilibrium & posture, perceives motion & spatial orientation, and stabilizes the eyes relative to external space during head movements. Two types of organs collectively form the vestibular system: 1) the semicircular canals, and 2) the otolith organs. The three semicircular canals share endolymph and provide three axis stabilization and information about angular acceleration. [Ref. 1:p.182] The otolith organs consist of two pairs of elliptical sacs called the utricle and saccule. These organs provide the CNS with information about linear

acceleration. Both angular and linear accelerations result in directionally specific eye movements, i.e. the body and eyes move in opposite directions to maintain a stable retinal image. [Ref. 1:p.185]

The apparent directions and orientations of visually presented objects depend on both retinal and extraretinal mechanisms [Ref. 1:p. 198].

Spatial locations and visual directions of objects are determined by an integration and interaction of the following processes:

1. retinal stimulation
2. information about the loci of retinal activity
3. position of eyes in their sockets
4. position of the head to trunk
5. position of trunk to torso
6. orientation of the entire body with respect to gravity. [Ref. 1:pp. 188-189]

2. Environmental vs. Egocentric Orientation

Gravity has a strong influence on all normal life on earth. Plants grow with their roots down, objects fall to the ground, and our "upright" position is with our feet on the ground. Under normal terrestrial circumstances, gravity provides our proprioceptive and vestibular systems with a constant and reliable source of information.

Vision also influences how we perceive the upright nature of our environment. We associate head up and feet down as upright, the ceiling as the top and the floor as the bottom of a room, and the sky above and the earth below. Vision is not as reliable a source of information concerning our posture or the position of other objects as we would like to believe. A simple illustration of how misleading visual information can be is the illusion in Figure 1 [Ref. 2:p. 125]. The figure shows that optically straight horizontal and

vertical lines can appear slanted or tilted. Man can more accurately judge vertical and horizontal positions of a line than any other positions, with his judgement of the vertical nearly twice as accurate as the horizontal (mean standard deviation of 0.28 vs. 0.52 degrees, respectively) [Ref. 3:pp. 179-180]. Although the world is not filled with predominately pure vertical and pure horizontal lines [Ref. 2:pp. 154-155], the enhanced accuracy with the vertical may be due to man's need for postural stability.

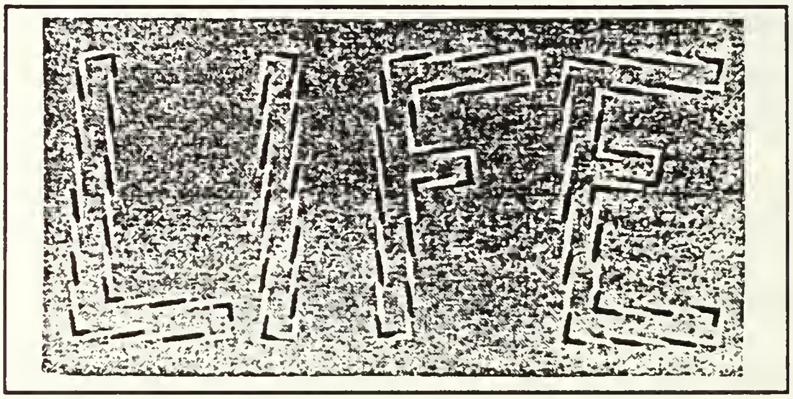

Figure 1. Visual Illusion

Human postural stability depends, to a large extent, on vision. The degree to which postural stability depends on vision varies with the age of the developing child, and begins to decrease constantly from five years old on. Brandt et al reported that "the normal adult shows only moderate body sway in the direction of visual motion." [Ref. 2:p. 396]

Asch and Witkin (1948) had subjects stand erect while observing a reflection of a scene in a tilted room. A mirror was used to separate visual and postural clues. Conflicting information about the orientation of a scene was then presented to each subject. This experiment showed that information provided by the visual framework practically dominated the

postural factors, despite the fact that subjects were told to use postural cues only. [Ref. 4:p. 335]

Fisher (1962) found that strong visual illusions can occur when vestibular and visual information regarding the tilt or rotation of the head are in conflict. This would indicate that vision is not completely practically dominant over the vestibular system. [Ref. 2:p. 459]

Mittelstaedt (1984) asked subjects to set a line of light to the vertical in an otherwise completely darkened room and found most people compromised the position of the line between gravitational vertical and their own head-to-foot body axis. He concluded that "visual information does not suppress the gravitational information, but rather forms a resultant with it." [Ref. 5:p. 1]

Stoper and Cohen (1986) reported that "studies investigating conflict between vision and gravity information in perception of the vertical or horizontal have indicated that the system supplying gravitational information is not suppressed, but rather, that there is a compromise between the visual and the gravitational systems" [Ref. 6:p. 315].

3. Cue Hierarchy

Stimuli or cues are always present. However, the particular set of stimuli we respond to is often determined by the task at hand. This is called the *hierarchy of cueing*. For example if you are eating, you generally do not pay attention to sound or gravitational-inertial forces, but concentrate on smell, vision, and taste. Similarly, a blind person, who is denied visual cues or stimuli, will pay close attention to sounds and smells that a sighted person would normally ignore. The relative importance given to specific cues often

depends on the task for which the cues are to be used and the relative usefulness of the cues in the performance of the task [Ref. 7:pp. 258-262].

4. Starting Position Effects

Environmental constants or constraints within a single modality are ***intrasensory constraints***. A ***norm*** is an additional constraint which is defined as "a uniquely specifiable value of a physical stimulus dimension which has a special behavioural significance." [Ref. 3:p. 10]

If you spend enough time exposed to stimuli that are off the norm, you will eventually perceive it as being more like the norm. Gibson reported:

> If a sensory process which has an opposite is made to persist by a constant application of its appropriate stimulus-conditions the quality will diminish in the direction of becoming neutral, and therewith the quality evoked by any stimulus for the dimension in question will be shifted temporarily towards the opposite or complementary quality. [Ref. 8:p. 223]

For example, if you look at a curved line for a prolonged period of time, it will appear less curved, and begin to approach the "norm" of "straightness." The process Gibson has just described is known as ***normalization***.

Asch and Witkin (1948) did a series of experiments on the perception of upright with displaced visual fields. In one of these experiments subjects entered the lab and saw the set-up including a tilted room; they sat in a chair that was tilted in the direction opposite to that of the room. Asch and Witkin found that if one looks at a tilted room long enough, one sees it as "upright." [Ref. 9:p. 461-462]

Takala (1951) had subjects place a variable line parallel to a standard line in the light and again in the dark.

Takala concluded that the horizontal is a stronger norm for judgments made in the light, and the vertical is a stronger norm for judgments made in the dark. [Ref. 3:p. 180]

In 1986 a bed rest study at the NASA AMES Research Center in Mountain View, California had nineteen subjects spend 30 days in a 6 degree head-down orientation. Upon being placed *horizontal* with respect to gravity, all subjects spontaneously reported that they now felt themselves to be in a head-up orientation. [Ref. 10] Taken together, these observations reenforce the notion that the initial starting positions affect how subjects perceive "true" body orientation.

5. The Effects of a Tilted Visual Field

Three aspects of spatial vision are environmental orientation, egocentric orientation, and egocentric direction. Environmental orientation is how objects appear to be oriented with respect to their environment. Objects will appear to be "... in line with or at variance from the vertical or horizontal dimensions of the world. The visual framework and the perceived direction of gravity are two major sources of environmental orientation." [Ref. 11:p. 7] Egocentric orientation is how one perceives the visual environment relative to oneself. [Ref. 11:p. 7] Is the hillside sloped toward or away from you? Egocentric direction is when an object has a certain radial direction relative to the observer. [Ref. 11:p. 7] Is the book in front of you or behind you?

A person in an upright posture in a stationary terrestrial environment receives concurrent and redundant information about his environmental and egocentric orientations. This redundancy may account for his accuracy in determining the orientation of objects. If the observer

either tilts his head or entire body, vertical objects appear to be tilted egocentrically in the opposite direction. [Ref. 9:p. 7]

In a normal 1-G environment, the eyes are oriented to maintain a particular elevation and direction of gaze. Figure 2 illustrates the possible relationships among the head, eyes, and an object with respect to the pitch axis. Note there is a 1:1 relationship between the θ_1 (head pitch angle) and θ_2 (eye elevation angle) but in opposite directions.

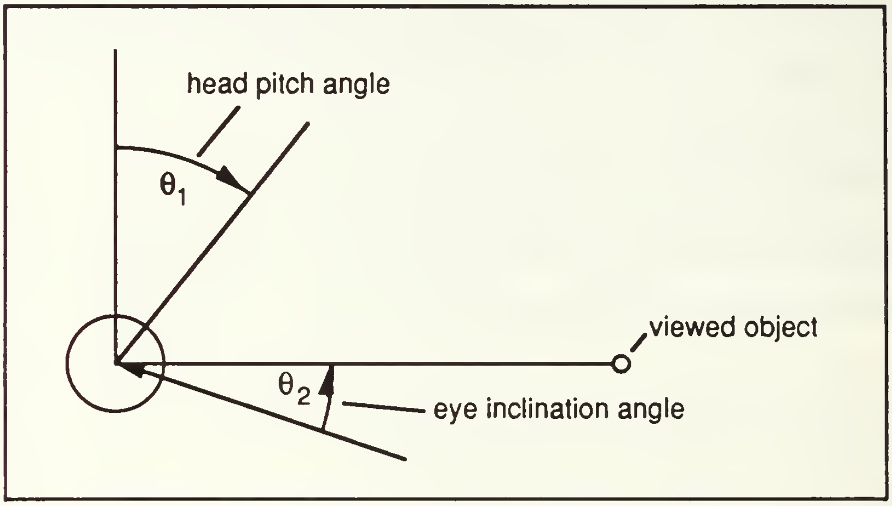

Figure 2. Real and Apparent Location of an Object

6. Gravitoinertial Forces on the Body

The three major axes and the corresponding eye positions for a normal standing observer are displayed in Table 1 and Figure 3.

a. The Effects of Yaw

The yaw ($\dot{Z}$) axis is normally parallel to the earth's gravitational field. Rotations about the Z axis do not change inputs to an observer with respect to gravity, but they are capable of causing a person to become unbalanced.

TABLE 1. GRAVITOINERTIAL FORCES ON A NORMAL STANDING OBSERVER

BODY AXIS	DIRECTION	ROTATION ABOUT AXIS	JUDGMENT wrt. GRAVITY
X	Chest-spine	$\dot{X}$ = Roll	Tilted left or right
Y	Left-right	$\dot{Y}$ = Pitch	Head pitched forward or backward
Z	Head-Toe	$\dot{Z}$ = Yaw	No change

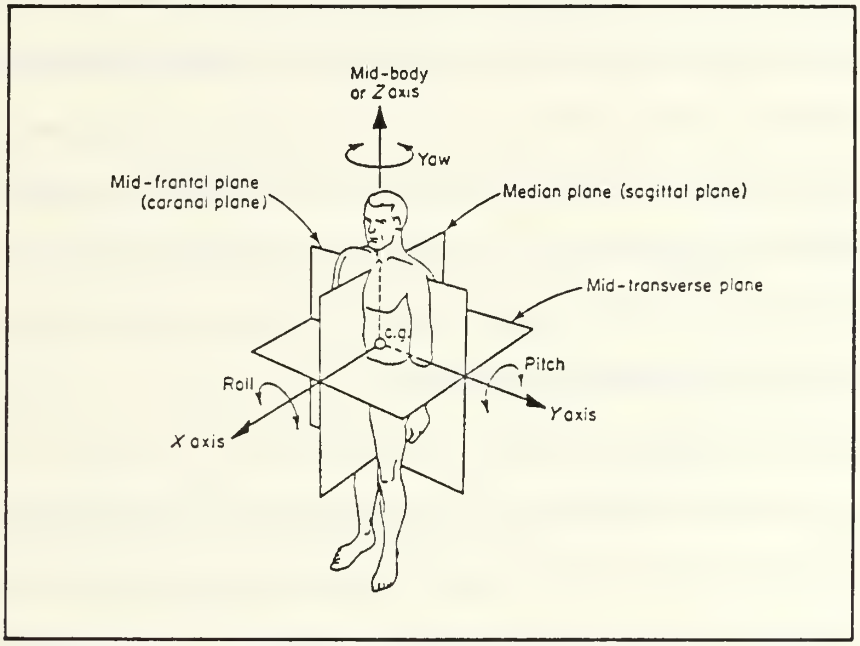

Figure 3. Body Coordinate System and Axes of Rotation

When a person rotates either in a revolving chair or by spinning, the eyes fix upon and attempt to maintain view of a certain object. This fixation initially results in the eyes moving in the opposite direction to that of the body. When the eyes have turned as far as possible and the object can no longer be seen, the eyes quickly move in the direction of the body rotation and fixate on another object. The slow movement of the eyes opposite to the

direction of rotation and the swift motion in the direction of rotation is called ***rotary nystagmus***. [Ref. 12:p. 171] The eye movements described above are in response to acceleration of angular motion. When the body continues to rotate at a constant velocity nystagmus ceases, but is resumed in the opposite direction to the original nystagmus when rotation stops. This is known as ***postrotary nystagmus*** [Ref. 12:p. 171], which can cause a person to feel dizzy and loose his/her balance.

Dancers avoid postrotary nystagmus and maintain their balance by using a technique called *spotting*. As they rotate they keep their eyes focused on the audience as long as possible, and then flick their head around faster than their turning body until it is once again facing the same way. By substituting rapid movements of the head for that of the eyes, the dancers have eliminated postrotary nystagmus and simultaneously subjected their vestibular system to alternating clockwise and counterclockwise stimulation as the head accelerate and decelerates.

b. The Effects of Roll

Most studies on how gravity effects perceived body position have been done about the roll ($\dot{X}$) axis. In 1861 Aubert noted that if subjects were tilted between 60 and 150 degrees, a luminous rod appeared to be tilted significantly in the opposite direction. This phenomenon is known as the "A" effect. [Ref. 13:p. 137] In 1916, Mueller noted that if a subject was tilted less than 60 degrees, a physically vertical line will often appear to be tilted a couple of degrees in the direction of the S's body. This phenomenon is known as the "E" effect. [Ref. 13:p. 137]

The two classic errors, the "A" and "E" effects, show that when given only gravitational cues, perception of visual-gravitational vertical is less accurate and less precise than when a visual framework was also provided. The error of the "A" effect is greater than the error of the "E" effect. [Ref. 13:pp. 137-138]

c. ***The Effects of Pitch***

Modern high performance aircraft and spacecraft are capable of stimulating the vestibular system to a degree that was impossible in naturally occurring terrestrial environments. This is most clearly demonstrated by the effects of linear accelerations on judgments of orientation about the pitch (Y) axis.

Visual perception can be altered by stimulation of the otolith organs or by changing the natural position of the eyes and motor impulses to the extrinsic eye muscle (which maintain foveal vision). The apparent location of objects in altered gravitational-inertial fields depends on the magnitude and direction of the altered field. [Ref. 1:p. 200] An example of visual illusions that pertain to the pitch environment is the ***oculogravic illusion***. The Oculogravic Illusion depends upon changes in both the magnitude and direction of gravitation-inertial forces. [Ref. 1:p. 200]

As a result of several A-7 carrier-based aircraft launch fatalities, a study using the human centrifuge Dynamic Flight Simulator at Naval Air Development Center was conducted.

> CATAPULT LAUNCHINGS of carrier-based aircraft expose the pilot to strong and sudden forward ($+G_X$) acceleration that can generate both visual and postural illusions. The visual, or oculogravic, illusion causes seen objects to appear to rise above their true physical positions, and the postural, or posturogravic, illusion causes the pilot to feel that his body is

> being tilted backwards. Because of these illusions, the pilot can become disoriented;the entire array of cockpit instruments may appear to rise, and the pilot may feel that his aircraft is climbing in an excessively high, nose-up, attitude. [Ref. 15:p. 797]

Pilots, who were given both a carrier takeoff director system (CTDS) and conventional instruments, reported both a reduced instrument scan workload and more accurate stick control. They also reported no disorientation. [Ref. 15:p. 801] The significance of studies like the above is that pilots who are aware of possible error-producing situations and are provided with flight instruments which are not only easy to monitor, but which also provide relevant information, can avoid disastrous results. [Ref. 15:p. 798]

Not only can pitch changes influence performance in the tactical environment, but it has also taken its toll in commercial aviation. Kraft (1969) stated:

> During the first eight years of commercial jet operations, that is, prior to 1967, approximately 16% of the major aircraft accidents occurred during night approaches over unlighted terrain or water toward well-lighted cities and airports. Meteorological conditions in all cases were such that the flight crew could have employed visual reference to light patterns on the ground. In 1967, the accident rate under similar conditions rose to 17.5%. Accidents involving highly instrumented aircraft continue to occur during seemingly safe night visual approaches. [Ref. 16:p 84]

Visual illusions created by the pitched terrain were the cause of the above mentioned "pilot errors." i.e. When the terrain had an upward slope the approach was too low and when only the airport was visible the approach was too high.

> ...[One of] the difficulties encountered by a pilot on an approach path was a poor set of visual cues--not the absolute minimum of dense fog but rather conditions that would lead him to trust an approach on Visual

Flight Rules when visual information is marginal or possibly misleading.The most obvious of these is the situation in which artificial sources of light provide the only visual stimuli. [Ref. 16:p. 85]

Clearly, visual and gravitoinertial inputs about the pitch axis have dramatic affects on spatial orientation. These affects can have profound consequences on aircraft and spacecraft operations.

II. NATURE OF THE PROBLEM

Proprioceptive inputs received in an altered "gravitational" environment, and visual inputs received when flying over steeply contoured terrain under certain conditions, can provide the pilot with erroneous information. This type of misinformation can degrade his ability to assess his own orientation with respect to the surrounding environment.

Although research in the field of pitch angles has been conducted for over 100 years, the relative importance of gravitational vs. visual inputs has not been quantified adequately. Knowledge of the magnitude and accuracy of judgments made from visual inputs, gravitational inputs, or both, can greatly enhance the ergonomic design of instrumentation and operational protocols for use in the altered G environments of tactical aviation and space operations.

The purpose of this study is to explore the mechanisms involved in human spatial orientation by answering the following questions:

1. How do judgments of body orientation about the pitch ($\dot{Y}$) axis using visual inputs compare to judgments made in the dark without visual inputs?
2. How do differently pitched visual frameworks affect judgments of body orientation?
3. Does the starting position of an observer affect his ability place his body horizontal or vertical with respect to gravity?
4. Is a different cue hierarchy used to determine vertical and horizontal body orientations?

The four experiments that comprise this thesis are summarized in Table 2.

TABLE 2. SUMMARY OF STUDY

EXPERIMENT	SETTINGS OF BODY	LIGHTS	PURPOSE
1 (H/L)	Supine/Horizontal (H)	ON(L)	Evaluate subject's ability to set body supine using visual and proprioceptive inputs
2 (H/D)	Supine/Horizontal (H)	OFF(D)	Evaluate subject's ability to set body supine without visual inputs
3 (V/L)	Erect/Vertical (V)	ON(L)	Evaluate subject's ability to set body erect using visual and proprioceptive inputs
4 (V/D)	Erect/Vertical (V)	OFF(D)	Evaluate subject's ability to set body erect without visual inputs

Experiments 1 (H/L) and 2 (H/D) were conducted to explore the ability of subjects to set themselves to be supine, while Experiments 3 (V/L) and 4 (V/D) were concerned with setting the body to be erect. Experiments 1 (H/L) and 3 (V/L) were conducted in the light and Experiments 2 (H/D) and 4 (V/D) were conducted in the dark. By eliminating light it was hoped to determine the relative importance of visual and proprioceptive inputs in setting the body to be horizontal or vertical.

The significance of positioning one's body about gravitational horizontal is not the same as the significance of positioning one's body about gravitational vertical. It was expected that this difference in significance would be manifested by the subject using different cuing hierarchies when orienting himself to the horizontal or to the vertical, with respect to gravity. It was also expected that a subject's initial starting position would affect where he perceives his true gravitational horizontal and true gravitational vertical to be located. When visual inputs and proprioceptive inputs provide

conflicting information, the subject's judgement may be determined by the "stronger" input, but it may also be compromised by the "weaker" input. i.e. There may be a "compromise" between the two sets of cues.

While gravitational inputs (via proprioceptive and extraretinal responses) may provide the stronger influence, visual inputs (via retinal responses) may alter the subject's response if the inputs are not harmonious.

III. MATERIALS & METHODS

A. SUBJECTS

Eight male and two female volunteer subjects participated in this study. They were between 17 and 52 years of age, were free of any apparent motor or vestibular abnormalities, and had apparent normal binocular vision. All ten subjects participated in all four experiments.

B. APPARATUS

A modified motorized Stryker CircOelectric hospital bed was surrounded by an independently supported frame, with the bed centered in the area provided by the frame (Figure 4). The orientation of the bed was measured from a scale displayed on the circular support of the bed (Figure 5).

A tilted box was constructed of foamboard panels mounted on an aluminum frame, which measured 279.4 cm (110 in) long by 121.92 cm (48 in) wide with a height of 167.64 cm (66 in). The orientation of the frame was provided by a protractor and pointer that were attached to the frame supports (Figure 6).

When the subject attempted to set his body supine, the apparatus was configured as shown in Figure 7. When the subject attempted to set his body erect in the light, a body brace and Elizabethan collar were used, as shown in Figure 8. The collar prevented the subject from seeing the bottom of the box and his feet, thereby eliminating visual cues that might provide additional information regarding his orientation. Because the collar tended to make subjects uncomfortably warm, a small fan was positioned near the foot of the

bed to provide additional ventilation and to prevent subjects from becoming overheated. When the subject attempted to set his body erect in the dark, only the brace was used.

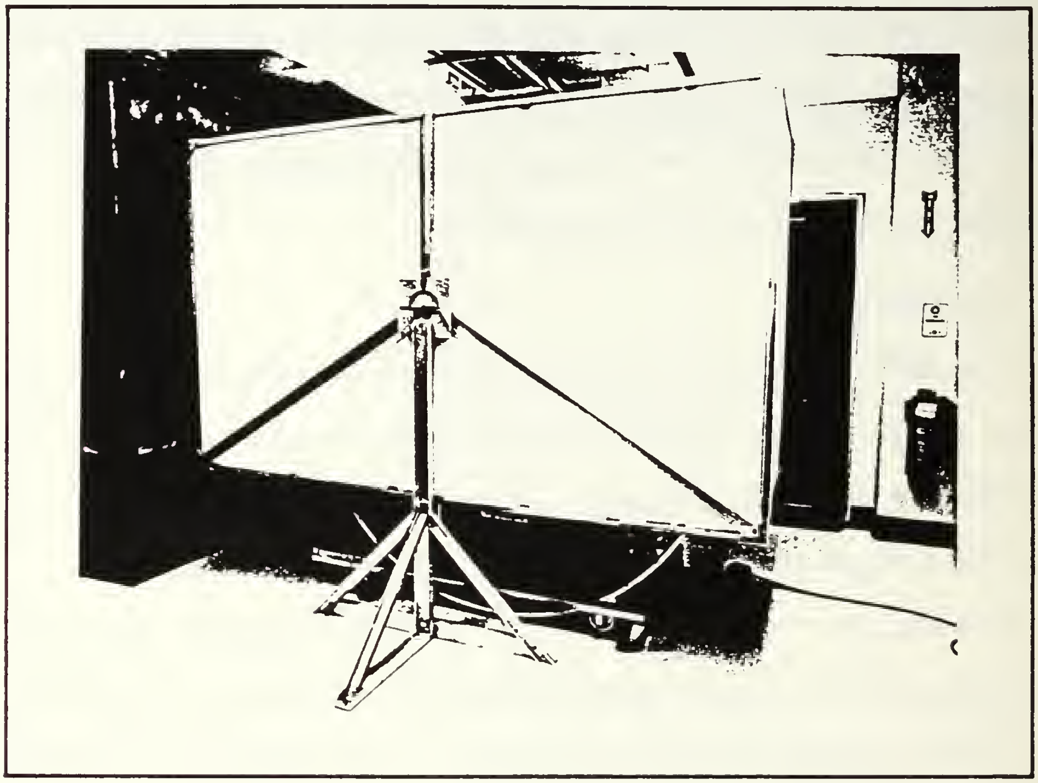

Figure 4. Apparatus

Experiments 1 (H/L) and 3 (V/L) used ambient room lighting. The 2 (H/D) and 4 (V/D) experiments were conducted in darkness. Subjects were also asked to keep their eyes closed throughout Experiments 3 (H/D) and 4 (V/D). The experimenter used a small flashlight to read and record bed and frame angle settings.

1. Instructions

Prior to the start of each experiment, subjects were shown the apparatus, read a set of instructions which explained that experiment

(Appendix A), and given the opportunity to ask questions. All subjects were instructed to make their adjustments based on their immediate perceptions and feelings, and not on any preconceived notions. All subjects stated that they complied with these instructions.

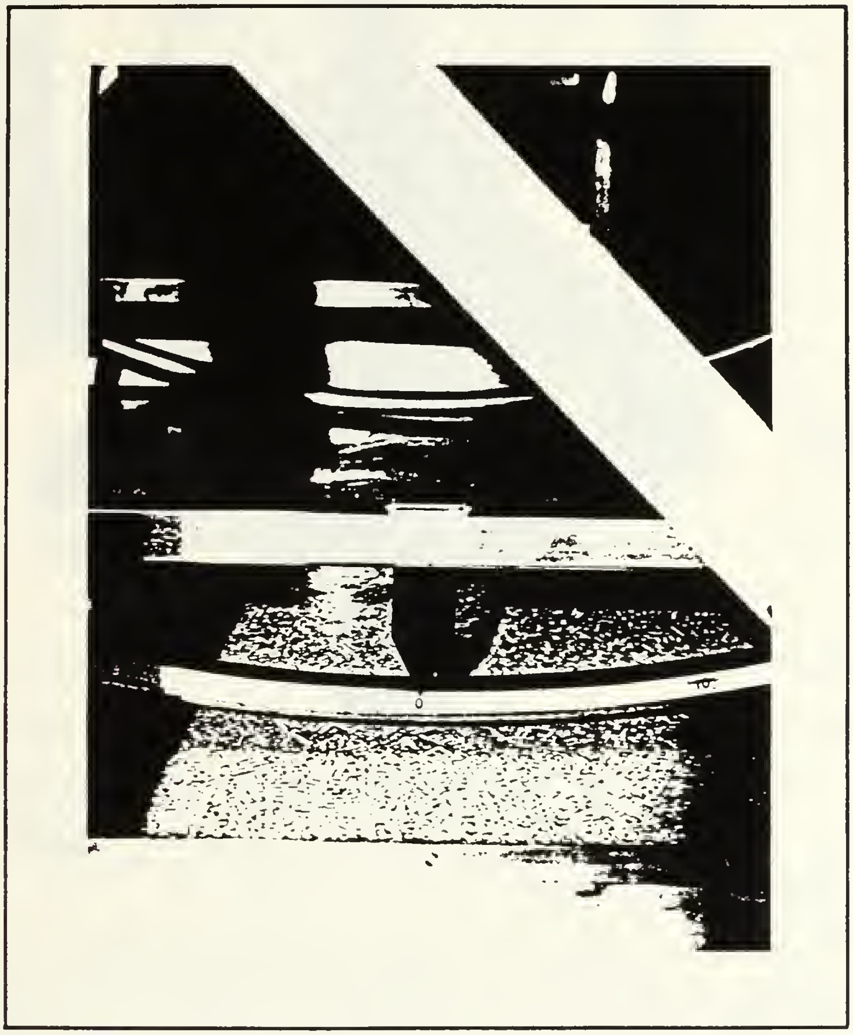

Figure 5. Scale on Bed

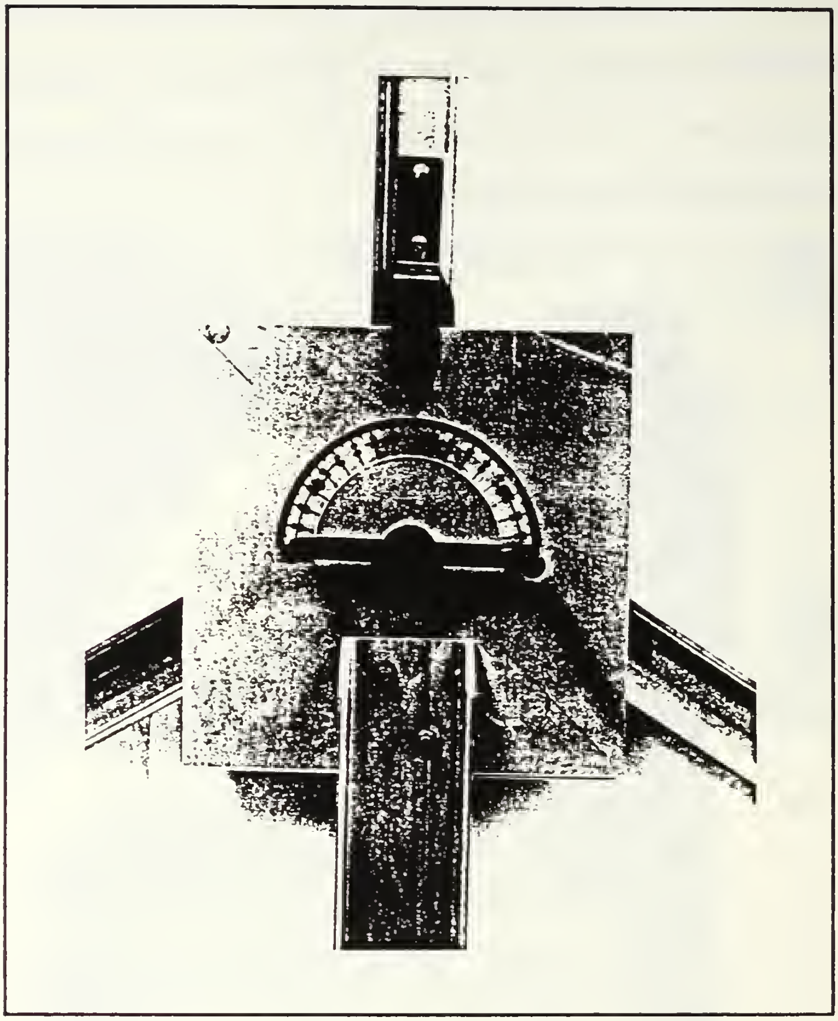

Figure 6. Protractor and Pointer on Frame Support

2. Experimental Protocol

Subjects participated in either the horizontal or the vertical experiments during the course of one session. During a preliminary study it was determined that subjects became restless and/or bored if they were confined in the bed more than the length of time for two experiments (approximately 45-60 minutes). Thus, only two experiments were conducted in a single session. A second session was conducted either several hours later the same day, or on another day.

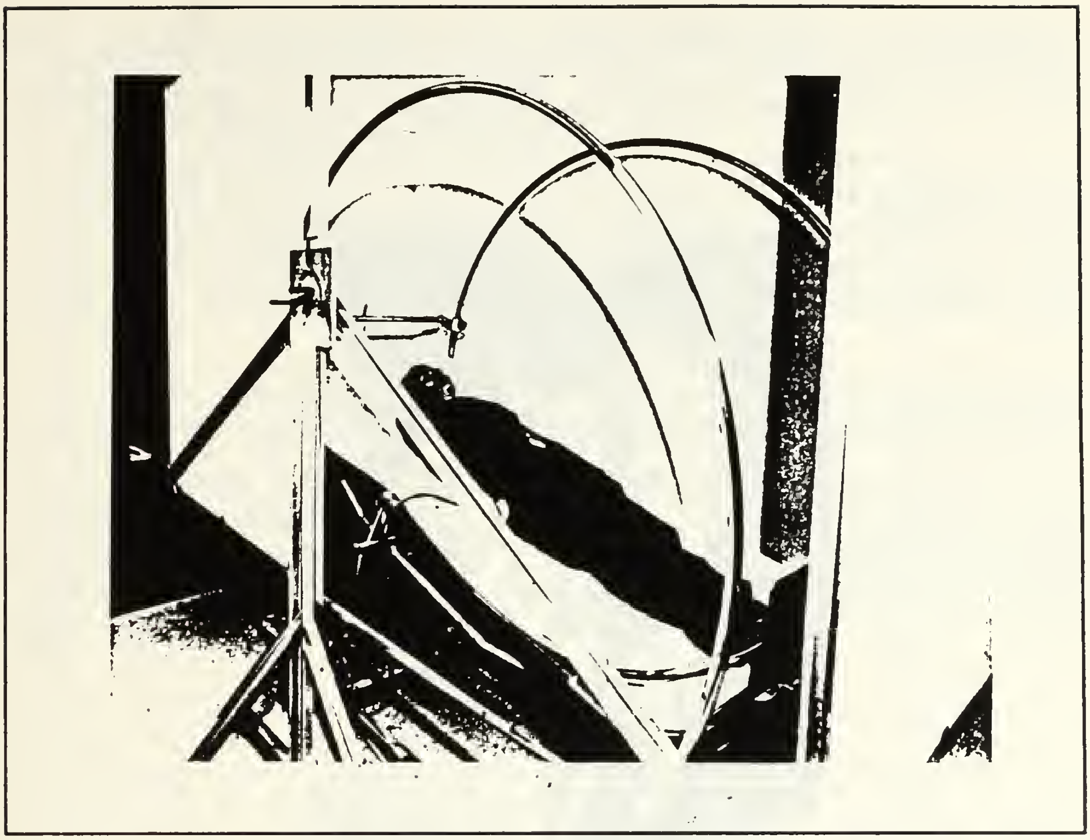

Figure 7. Cutaway View Without Collar & Brace

Initial positions for the frame and for the bed were randomly selected. Once assigned, the subject started with the same initial frame orientation for each experiment, according to a Latin Square Design in which all subjects experienced all five orientations of the frame. The frame angle settings were -15, -7.5, 0, +7.5, and +15 degrees from the "horizontal" (H/L & H/D) or from the "vertical" (V/L & V/D). The pitch of the frame was changed after four settings were made by the subject. The subject's settings were initiated from counter-balanced starting positions of the body, which were -15, +15, +15, and -15 degrees from the horizontal or the vertical, depending on the experiment. The first time at each starting position was designated as Trial 1, and the

second time at that starting position was designated as Trial 2. After each setting, the deviation from true horizontal or true vertical was recorded.

Figure 8. Cutaway View With Collar & Brace

As noted previously, in Experiments 1 (H/L) and 2 (H/D), subjects lay on the bed without the brace or collar. In Experiments 3 (V/L) and 4 (V/D), the brace was used. In Experiment 3 (V/L), both the brace and the collar were used. Subject was handed the bed control and allowed to test its responsiveness before the start of the actual experiment. Each trial of each experiment consisted of the following:

1. The subject was asked to close his/her eyes, while the experimenter adjusted the frame and when the subject oriented the bed into the starting position (±15 degrees from gravitational horizontal or vertical) as per the experimenter's instructions.
2. The subject was asked to open his/her eyes and, while keeping his/her head on the mattress, look at the frame. After 15 seconds, the subject was asked to place himself/herself horizontal (or vertical) with respect to gravity (i.e. supine or erect) and tell the experimenter when he/she was done.
3. The subject was asked to report if he/she could not accurately position his/her body, and if not which direction would have been preferred.[1]
4. In Experiment 2 (H/D) (or 4 (V/D)), the subject was asked to keep his/her eyes closed throughout the entire experiment instead of only between settings, but was still given 15 seconds between orienting the bed to the starting position and positioning it to gravitational horizontal (or vertical).

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[1]All subjects reported that they were able to position their body where they wanted.

IV. RESULTS

Table 3 shows a general summary of the mean deviations from horizontal or vertical body positions in the light and in the dark for all ten subjects across all four experiments. Individual subject data can be found in Appendix B.

TABLE 3. MEAN DEVIATION FROM GOAL (H OR V) ORIENTATION IN DEGREES

EXPERIMENT	BOX TILT FROM H OR V (DEGREES)				
	-15	-7.5	0	+7.5	+15
1 (H/L)	0.76	1.69	3.05	2.97	2.76
2 (H/D)	0.23	-0.08	1.72	0.58	0.86
3 (V/L)	-3.04	-2.84	-2.28	-2.12	-1.84
4 (V/D)	-3.09	-3.37	-3.41	-3.47	-3.91

A Four Way repeated measures ANOVA was performed on data from each of the experiments. The independent variables analyzed in each ANOVA were box tilt (BT) angle (by pitching the frame which surrounded the bed), trial order (T) (first time vs second time at either ±15 degree body tilt), the subject's body starting positions (SP), and subjects. Detailed data analyses for each of the four experiments are presented in the following sections.

A. EXPERIMENT 1 (H/L): GRAVITATIONAL HORIZONTAL IN LIGHT

Table 4 shows that box tilt angle, which accounted for 4.84% of the variance, had the only statistically significant effect [$F(4,36) = 3.56$, $pH0 < .05$]. As shown in Figure 9, settings of body to horizontal in light indicate that there is a trend

for the subject to set himself more positive as the angle of the box tilt increases between -15 and 0 degrees. Statistically significant differences among all box angle settings were determined by a Duncan Multiple Range Statistic. The results, as shown in Table 5, indicate that the only statistically differences among data points are between angles; -15 and +15, -15 and +7.5, and -15 and 0 degrees.

TABLE 4. SUMMARY OF ANOVA HORIZONTAL (LIGHT): EXPERIMENT 1

	DF	SSQ	MSQ	F Ratio[1]	P (H_0)	% Variance
Box tilt angle (BT)	4	157.46	39.36	3.56	<.05	4.84
Trials (T)	1	4.74	4.74	2.40	—	0.15
Start POS (SP)	1	96.33	96.33	2.99	—	2.96
BTxT	4	7.85	1.96	0.79	—	0.24
BTxSP	4	42.47	10.62	2.36	—	1.30
TxSP	1	1.34	1.34	1.19	—	0.04
BTxTxSP	4	12.32	3.08	1.06	—	0.38
Subjects (S)	9	1861.40	206.82	—	—	57.17
SxBT	36	398.01	11.06	—	—	12.22
SxT	9	17.76	1.97	—	—	0.55
SxSP	9	289.94	32.2	—	—	8.91
SxBTxT	36	89.73	2.49	—	—	2.76
SxBTxSP	36	161.69	4.49	—	—	4.97
SxTxSP	9	10.18	1.13	—	—	0.31
SxBTxTxSP	36	104.59	2.91	—	—	3.21
TOTALS	**199**	**3255.82**				**100.00**

[1]F-RATIO is defined by MSQ(Source)/ MSQ(Source x S).

TABLE 5. DUNCAN MULTIPLE RANGE TEST

	ANGLES (DEGREES)				
	-15	-7.5	+15	+7.5	0
MEANS	0.76	1.69	2.76	2.97	3.05
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TABLE 6. SUMMARY OF ANOVA HORIZONTAL (DARK): EXPERIMENT 2

	DF	SSQ	MSQ	F Ratio	P (H_0)	% Variance
Box tilt angle (BT)	4	75.85	18.96	2.37	—	2.42
Trials (T)	1	7.18	7.18	0.81	—	0.23
Start POS (SP)	1	60.39	60.39	1.16	—	1.92
BTxT	4	56.00	14.00	2.03	—	1.78
BTxSP	4	2.49	0.62	0.13	—	0.08
TxSP	1	5.48	5.48	1.71	—	0.17
BTxTxSP	4	7.32	1.83	0.74	—	0.23
Subjects (S)	9	1555.43	172.83	—	—	49.54
SxBT	36	288.50	8.01	—	—	9.19
SxT	9	79.60	8.84	—	—	2.54
SxSP	9	467.88	51.99	—	—	14.90
SxBTxT	36	248.73	6.91	—	—	7.92
SxBTxSP	36	167.56	4.65	—	—	5.34
SxTxSP	9	28.90	3.21	—	—	0.92
SxBTxTxSP	36	88.57	2.46	—	—	2.82
TOTALS	199	3139.89				100.00

C. EXPERIMENT 3 (V/L): GRAVITATIONAL VERTICAL IN LIGHT

As shown in Table 7, SP, which accounted for 11.17% of the variance, had a statistically significant effect: F(1,9) = 19.40, PH0 < 0.01. Ts, which accounted for only 0.94% of the variance also had a statistically significant effect: F(1,9) = 5.82, PH0 < 0.05. Unlike Experiment 1(H/L), BT had no statistically significant influence on settings of body orientation.

TABLE 7. SUMMARY OF ANOVA VERTICAL (LIGHT): EXPERIMENT 3

	DF	SSQ	MSQ	F Ratio	P (H_0)	% Variance
Box tilt angle (BT)	4	39.83	9.96	0.57	—	1.52
Trials (T)	1	24.71	24.71	5.82	<0.05	0.94
Start POS (SP)	1	293.06	293.06	19.04	<0.01	11.17
BTxT	4	31.05	7.76	2.10	—	1.18
BTxSP	4	5.34	1.33	0.35	—	0.20
TxSP	1	2.35	2.35	0.82	—	0.09
BTxTxSP	4	12.23	3.06	0.88	—	0.47
Subjects (S)	9	989.42	109.94	—	—	37.71
SxBT	36	632.21	17.56	—	—	24.10
SxT	9	38.21	4.25	—	—	1.46
SxSP	9	135.94	15.10	—	—	5.18
SxBTxT	36	132.82	3.69	—	—	5.06
SxBTxSP	36	135.37	3.76	—	—	5.16
SxTxSP	9	25.82	2.87	—	—	0.98
SxBTxTxSP	36	125.33	3.48	—	—	4.78
TOTALS	**199**	**2623.68**				**100.00**

Figure 10, which shows how SP affects subjects' ability to set themselves V/L, appears to indicate that subjects were much more accurate at setting themselves vertical from +15 than from –15 degrees. Although subjects

generally set their body head-back (i.e. negative) in both trials 1 and 2 (Figure 11), the settings for trial 1 appears to be more negative than for trial 2. This phenomenon may indicate a trend by subjects to improve their ability to set the body vertical with successive trials.

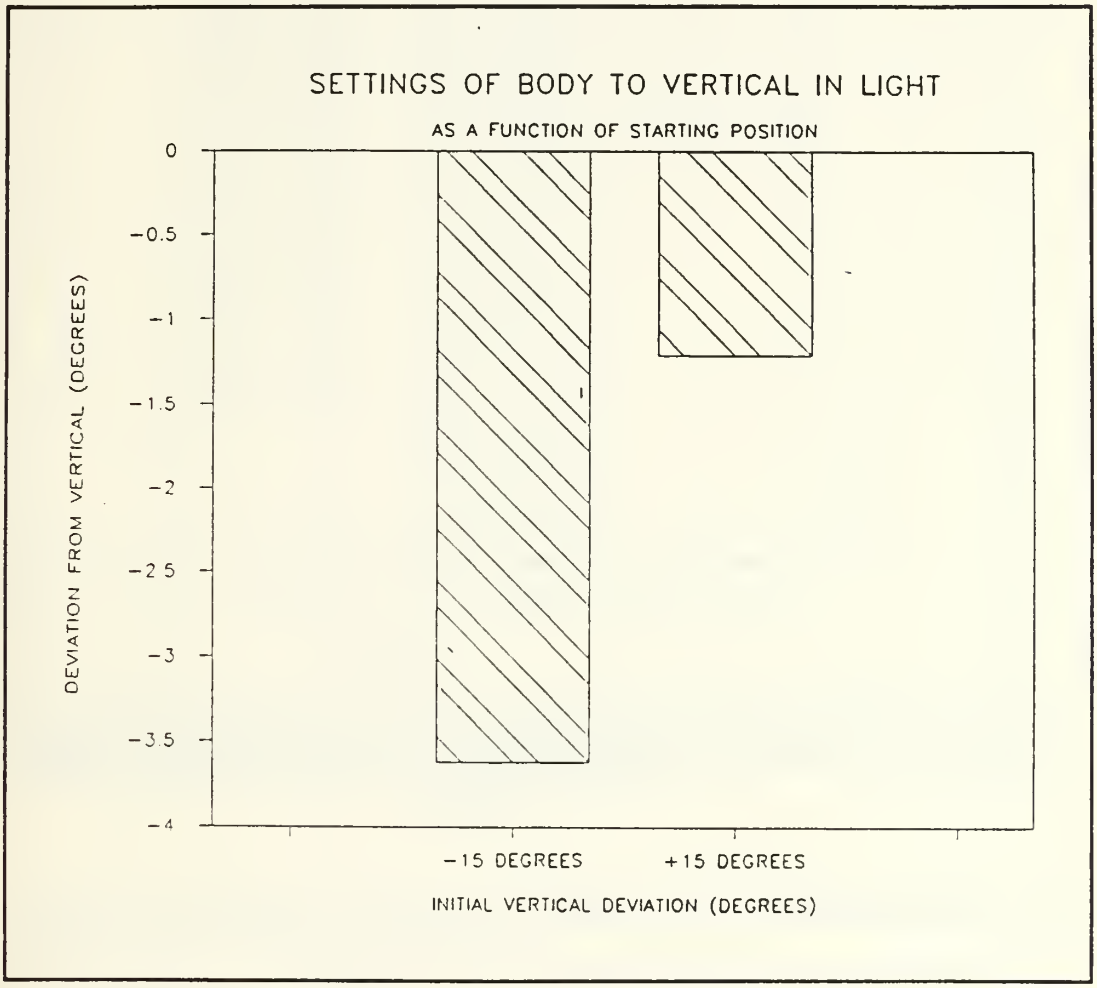

Figure 10. Setting of Body to Vertical as a Function of Starting Position (IN LIGHT)

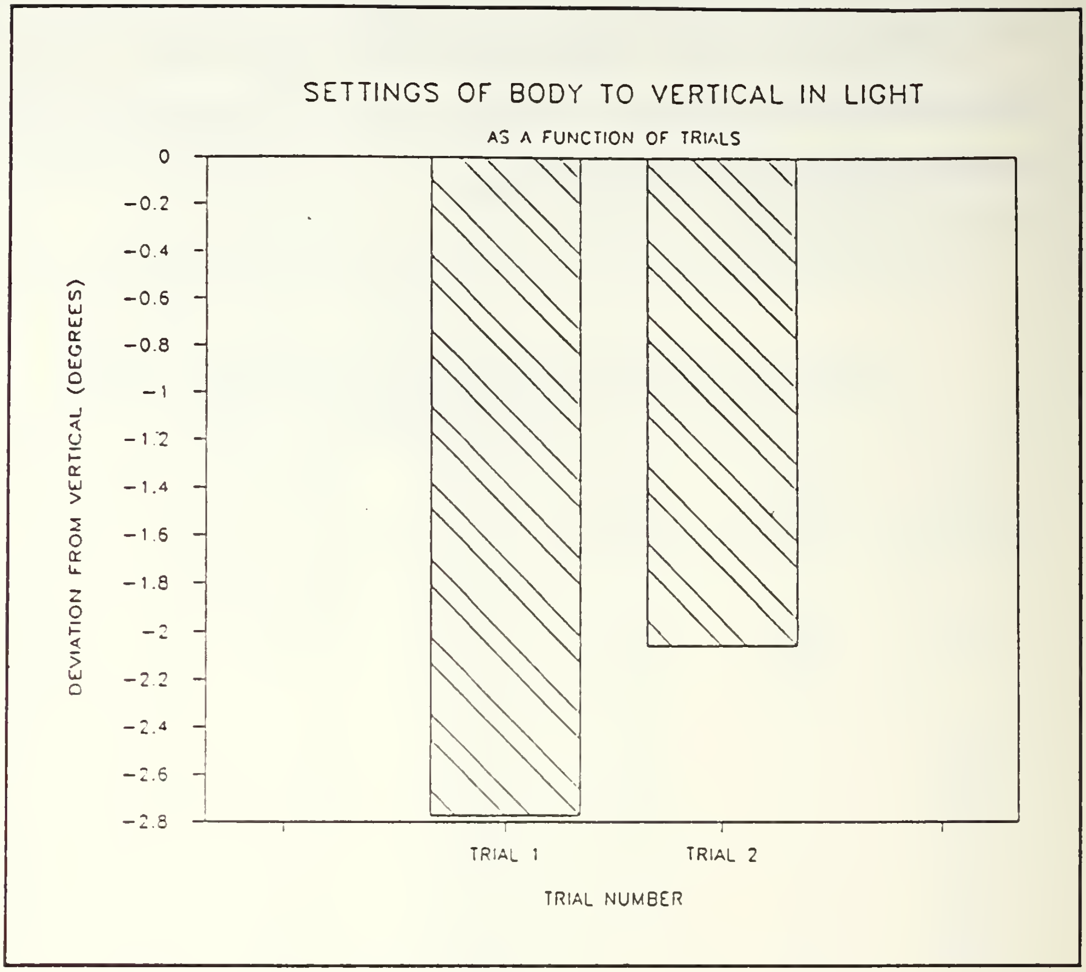

Figure 11. Setting of Body to Vertical as a Function of Trial Number (IN LIGHT)

D. EXPERIMENT 4 (V/D): GRAVITATIONAL VERTICAL IN DARK

Both SP and T had statistically significant effects on setting the V/D [$F(1,9) = 12.31$, and $F(1,9) = 12.43$, respectively]. See Table 8. SP accounted for 18.51% of the variance, and T for 2.00% of the variance. Figures 12 and 13 show that both SP and Ts have the same general trends in Experiment 4 (V/D) as they did in Experiment 3 (V/L).

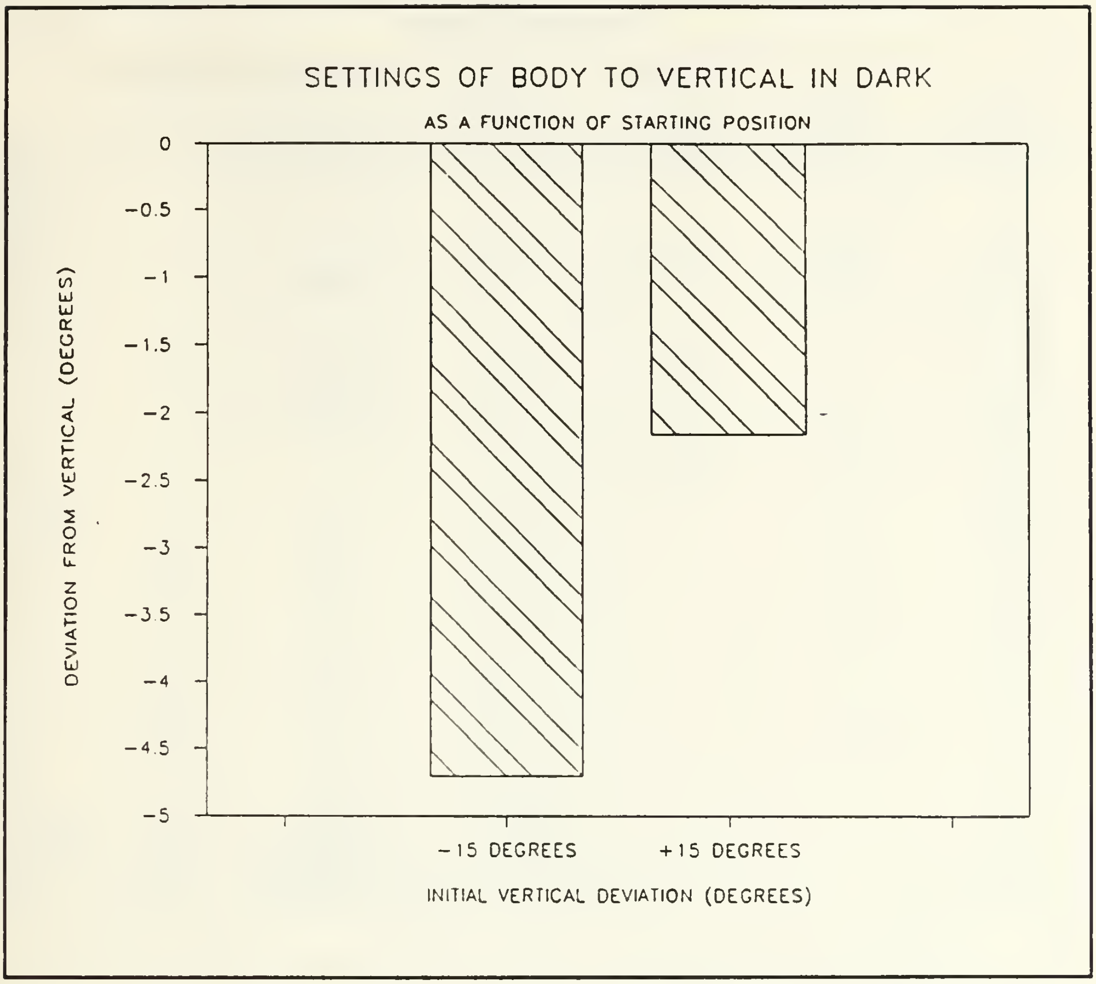

Figure 12. Setting of Body to Vertical as a Function of Starting Position (IN DARK)

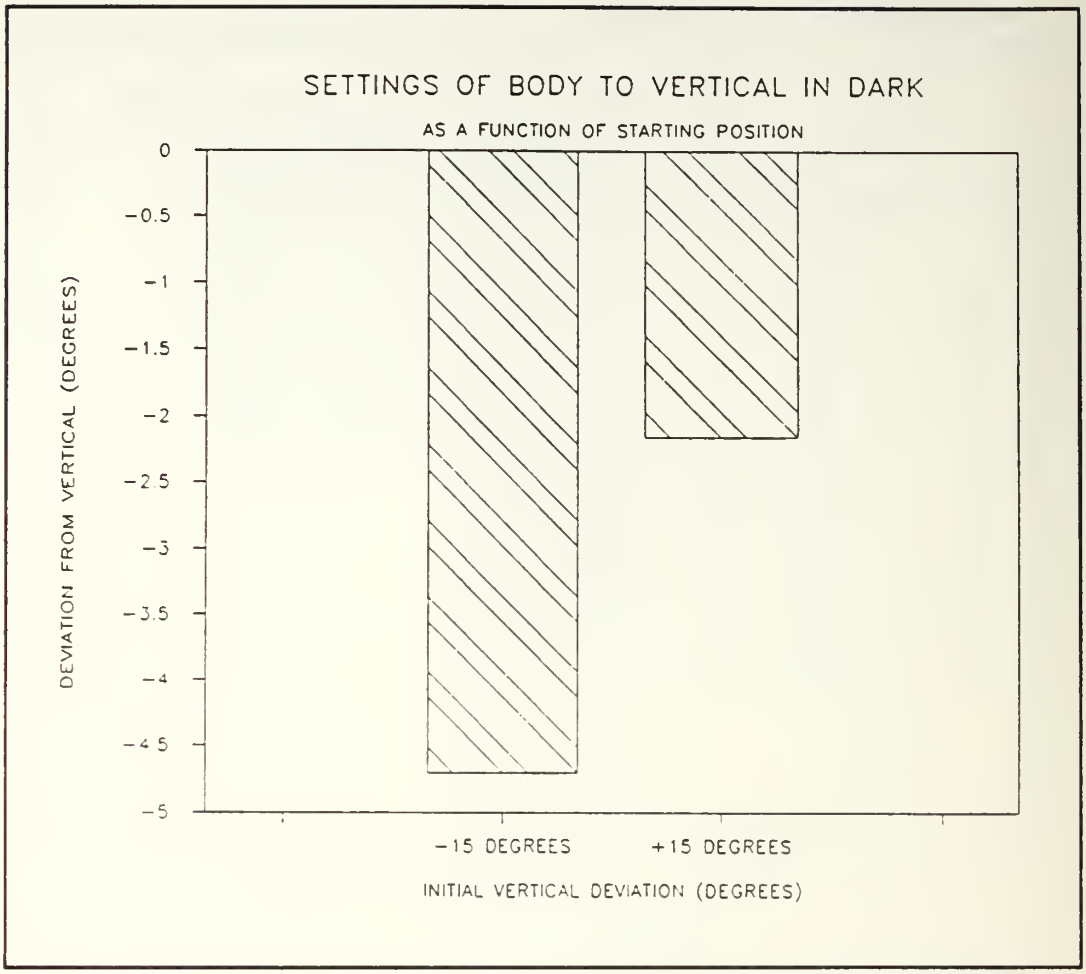

Figure 13. Setting of Body to Vertical as a Function of Trial Number (IN DARK)

TABLE 8. SUMMARY OF ANOVA VERTICAL (DARK): EXPERIMENT 4

	DF	SSQ	MSQ	F Ratio	P (H_0)	% Variance
Box tilt angle (BT)	4	13.92	3.48	0.75	—	0.81
Trials (T)	1	34.61	34.62	12.43	<0.01	2.00
Start POS (SP)	1	320.05	320.05	12.31	<0.01	18.51
BTxT	4	13.99	3.50	0.99	—	0.81
BTxSP	4	12.54	3.13	1.38	—	0.73
TxSP	1	7.30	7.30	2.57	—	0.42
BTxTxSP	4	9.30	2.32	0.92	—	0.54
Subjects (S)	9	566.81	62.98	—	—	32.79
SxBT	36	166.27	4.62	—	—	9.62
SxT	9	25.07	2.79	—	—	1.45
SxSP	9	233.96	26.00	—	—	13.53
SxBTxT	36	126.74	3.52	—	—	7.33
SxBTxSP	36	81.62	2.27	—	—	4.72
SxTxSP	9	25.50	2.83	—	—	1.48
SxBTxTxSP	36	90.91	2.53	—	—	5.26
TOTALS	199	1728.58				100.00

V. DISCUSSION

A. GENERAL DISCUSSION OF RESULTS

The accuracy of human judgments made from gravitational inputs, or both visual and gravitational inputs were evaluated in this study by having subjects set their body to gravitational horizontal or gravitational vertical in the dark and in the light. Additionally, both starting position and box tilt were varied while visual sensory inputs were either provided or denied throughout the study.

Under normal terrestrial conditions, humans are able to process information from various sensory inputs and to determine correctly the spatial orientation of other objects as well as their own orientation. The inertial forces provided by aviation and space travel enables the human to receive sensory inputs that differ from those to which his biological processing system is calibrated. This can lead to misinterpretation and judgement errors in determining spatial locations. These errors, which are consistent in neither magnitude nor direction, are also influenced by the task to be performed. The effects of cue hierarchy were evidenced in this study. Although all subjects reported that they knew the box was tilted and that they ignored its position when setting their body to gravitational horizontal, the orientation of the box had a significant effect on their settings in Experiment 1 (H/L). The implication is that, even if subjects believe they are not using visual information, this information can lead to errors in judgments of orientation. In Experiment 2 (H/D), there were no significant effects from any

of the parameters evaluated. This is not surprising, since light would be needed for visual inputs to have an effect. In naturally occurring situations, when humans set themselves horizontal or semi-horizontal it is generally to lie down. In most instances this task does not pose a threat to balance or equilibrium, and once accomplished, the situation is stable. Since this is not a dynamic function, the continuous processing of inputs is not needed to maintain orientation.

When the task was to set the body to gravitational vertical (Experiments 3 (V/L) and 4 (V/D)), both practice (Ts) and starting body position (SP) played significant roles. The orientation of the box had virtually no influence on setting the body to "vertical." The differentiation among cues is a function of the task at hand. Setting the body vertical is a dynamic function and involves continuous processing of proprioceptive and visual inputs to maintain body orientation.

Subjects asked to set themselves supine had a mean deviation of +1.45 degrees, indicating a head-high orientation, while subjects asked to set themselves erect had a mean deviation of -2.94 degrees, indicating a head-back orientation. The difference in magnitude and direction of these judgement errors may again be related to situations most commonly found in everyday life. The act of setting the body supine is most closely associated with resting. Most people tend to use one or more pillows when sleeping in bed. Those who relax in a reclining chair, still maintain a head high attitude. The norm resulting from this relationship is a slightly head-high orientation produced by the support of a "pillow." This *Pillow Effect* may account for the

resulting positive attitude when subjects set themselves to the gravitational horizontal.

Unlike setting the body supine, subjects associate setting the body erect to the dynamic interactions involved in maintaining their body in an upright posture. Since it appears that most people fall forward rather than backward, positive judgement errors would have simulated falling, and appear to have been avoided. Negative body positions are not uncommon and are seen, for example, when people lean against walls. Negative variations of erect are accepted as the norm and account for the -2.94 degree mean deviation from gravitational vertical.

This study suggests that differences in cue hierarchy lead to judgment errors that differ in magnitude and direction when subjects set themselves supine or erect. Ballinger studied the effects of a pitched visual field on eye level judgments by having subjects make either verbal or pointing responses. Verbal judgment responses were more strongly influenced by the pitched visual field than were the pointing responses [Ref. 11:p. 62]. The reason verbal judgment errors may have differed from pointing judgment errors is because pointing gives subjects additional cues that are not received when subjects only make verbal judgments. The act of reaching involves proprioceptive feedback, so when subjects reach, they "feel" where the arm is. In contrast, the present study examined the effects of a pitched visual field on whole body orientation responses, and not only those of the arm. When subjects were asked to set their body horizontal, the box had a "moderate" effect on their judgments. When subjects were asked to set their body vertical there were no statistically significant effects of the pitched field. The

differences in settings once again may relate to whether or not dynamic interactions are needed to maintain postural stability. Vertical adjustments of the body can give strong proprioceptive cues. To maintain balance, we need to constantly monitor these cues provided by the muscle spindles and by pressures on the feet. The effects of a pitched visual field are lessened because vision is less important to maintain balance when compared to the more numerous and "stronger" proprioceptive cues.

Although Ballinger's study involved only pointing responses, and this study involved whole body responses, they are similar in that the magnitude of judgement errors was directly related to the function or tasks performed by subjects. Further research studies need to be conducted to investigate the strength of the trends found in this study. Unlike Ballinger's work, in which all subjects followed the "model" mean, this study showed strong individual differences. This may be partially due to the non-naive sample population, who although unaware, were biased by their expectations.

More research is needed to answer the following questions: What are the effects of an altered gravitational field on a pitched observer? How long after an observers are exposed to a pitched visual field are they still affected by the field? How long does it take for observers to become adapted to their initial starting position?

B. APPLICATION

People are often exposed to pitched visual fields. Examples of these situations include sailors on ships or in submarines, aircraft pilots, and astronauts. [Ref. 11:p. 40] Whether or not a person is affected by a pitched visual field may be a function of body position as we have shown, yet a

certain body orientation may be needed for other reasons. For example, a person in a horizontal body orientation has a higher G-tolerance than one who is in a vertical body orientation. Therefore, under certain conditions, such as an astronaut reentering the earth's atmosphere, it may be necessary to place a person in a horizontal orientation so that a higher G-loading can be withstood. This study strongly suggests that people in a horizontal body orientation are affected by pitched visual fields, and must rely on instruments rather than visual inputs to correctly judge "true" orientation.

Other situations may require a person to maintain a vertical body orientation. A person in a vertical body orientation (e.g., a pilot flying off a carrier) might be affected more by what he "feels" than what he sees. Cohen (1977) found that pilots perceived a nose-high attitude because of the additional G-loading when catapulted off a carrier. The additional G-loading produced by the catapult launch introduced strong proprioceptive inputs which resulted in errors of pitch orientation.

In the current study, we have demonstrated that, where proprioceptive cues appear to be more critical (e.g., setting the body erect), visual cues have no significant influence on settings of body orientation. When proprioceptive cues seem to be less critical (e.g., setting the body supine), visual cues do have a significant effect on settings of body orientation. In the microgravity environment of space, there are no relevant proprioceptive cues regarding spatial orientation. Under these conditions, only visual cues provide relevant information. Thus, on the basis of the current study, we would expect the visual framework alone to determine judged body orientations in space. Any differences seen in this study between setting the

body horizontal or vertical, if done in space, where the visual framework alone is provided, should no longer be present.

If, following prolonged exposure to microgravity, gravitational forces are again introduced, and become relevant for orientation, the use of vision alone may no longer be appropriate, and errors of orientation judgments may emerge.

APPENDIX A: INSTRUCTIONS

1. SET BODY TO HORIZONTAL WRT GRAVITY

You will keep your eyes closed until you are asked to open them. I will orient the frame surrounding you and the bed; and have you use the control to move the bed until I tell you to stop. When instructed to so, you will open your eyes and have a few seconds to look around the room. Please keep your head on the mattress and do not try to look over the edge of the bed or under the frame. You will then be told to use the bed control to position your body so you are parallel to the floor. Please relax and take your time. If you feel that you can not accurately position the bed, set it as close as possible and tell me how different you feel you are from the desired position. Do you have any questions about this experiment or what I have asked you to do?

You may now use the bed control to get a feel for the responsiveness of the bed to the control. [Experimenter will wait one or two minutes to allow subject to get comfortable.] Are you comfortable? Do you have any questions before we start?

2. SET BODY TO HORIZONTAL WRT GRAVITY (IN DARK)

This is just like the first experiment, except you will be in the dark. You will keep your eyes closed throughout this entire experiment. I will orient the frame surrounding you and the bed; and have you use the control to move the bed until I tell you to stop. When instructed to so, you will use the bed control to position your body so you are parallel to the floor. Please relax and take your time. If you feel that you can not accurately position the bed,

set it as close as possible and tell me how different you feel you are to the desired position. Do you have any questions about this experiment or what I have asked you to do?

You may now use the bed control to get a feel for the responsiveness of the bed to the control. [Experimenter will wait one or two minutes to allow subject to get comfortable.] Are you comfortable? Do you have any questions before we start?

3. SET BODY TO VERTICAL WRT GRAVITY

You will keep your eyes closed until you are asked to open them. After you are comfortably secured in the bed I will ask you to place this collar on like so. [Experimenter demonstrates.] I will orient the frame surrounding you and the bed; and have you use the control to move the bed until I tell you to stop. When instructed to so, you will open your eyes and have a few seconds to look around the room. Please keep your head on the mattress. You will then be told to use the bed control to position your body so you are vertical to the floor i.e. feel that you are standing up straight. Please relax and take your time. If you feel that you can not accurately position the bed, set it as close as possible and tell me how different you feel you are from the desired position. Do you have any questions about this experiment or what I have asked you to do?

You may now use the bed control to get a feel for the responsiveness of the bed to the control. [Experimenter will wait one or two minutes to allow subject to get comfortable.] Are you comfortable? Do you have any questions before we start?

4. SET BODY TO VERTICAL WRT GRAVITY (IN DARK)

This is just like the last experiment, except you will be in the dark and will not have to wear the collar. You will keep your eyes closed throughout this entire experiment. I will orient the frame surrounding you and the bed; and have you use the control to move the bed until I tell you to stop. When instructed to so, you will use the bed control to position your body so you are vertical to the floor, or feel that you are standing up straight. Please relax and take your time. If you feel that you can not accurately position the bed, set it as close as possible and tell me how different you feel you are to the desired position. Do you have any questions about this experiment or what I have asked you to do?

You may now use the bed control to get a feel for the responsiveness of the bed to the control. [Experimenter will wait one or two minutes to allow subject to get comfortable.] Are you comfortable? Do you have any questions before we start?

APPENDIX B.

TABLE 1. INDIVIDUAL MEAN DEVIATIONS FROM GRAVITATIONAL HORIZONTAL (H/L & H/D)

	ANGLES (Degrees)				
SUBJECTS	**-15**	**-7.5**	**0**	**+7.5**	**+15**
LS1 L	-4.05	-2.00	-1.10	-1.75	-0.15
LS1 D	-0.98	-3.20	-2.88	-1.93	-0.45
LS2 L	-3.35	-1.20	-2.38	-3.78	-5.45
LS2 D	-3.28	-1.53	-1.93	-2.28	-2.28
LS3 L	-0.43	-1.75	3.53	1.85	0.60
LS3 D	-6.05	-4.80	0.98	-1.60	-3.40
LS4 L	1.75	1.78	3.80	6.75	5.50
LS4 D	-1.45	-2.78	2.08	2.08	0.88
LS5 L	-1.50	0.33	2.75	6.48	5.30
LS5 D	-0.85	-2.88	-2.58	-2.88	0.23
LS6 L	2.05	3.25	2.83	3.50	4.20
LS6 D	3.88	3.35	3.13	2.18	2.45
LS7 L	0.50	2.83	3.13	2.28	-0.70
LS7 D	0.52	-0.63	1.08	-0.55	-0.08
LS8 L	7.33	8.23	7.85	8.78	9.30
LS8 D	5.13	4.68	7.93	5.38	3.25
LS9 L	4.10	3.15	4.63	0.95	3.18
LS9 D	3.28	2.18	4.88	3.38	4.13
LS10 L	1.23	2.33	5.45	4.68	5.78
LS10 D	2.10	4.78	4.48	2.05	3.90
GRM L	0.76	1.69	3.05	2.97	2.76
GRM D	0.23	-0.08	1.72	0.58	0.86

TABLE 2. INDIVIDUAL MEAN DEVIATIONS FROM GRAVITATIONAL VERTICAL (V/L & V/D)

	ANGLES (Degrees)				
SUBJECTS	**-15**	**-7.5**	**0**	**+7.5**	**+15**
LS1 L	-3.00	-1.60	-1.10	-0.43	0.00
LS1 D	-2.88	-3.45	-2.25	-2.83	-2.83
LS2 L	-1.75	-5.13	-3.38	-4.95	-5.05
LS2 D	-1.28	-4.10	-3.45	-1.30	-3.63
LS3 L	-10.30	-7.70	-3.63	-1.68	-0.65
LS3 D	-6.05	-4.83	-5.63	-6.00	-4.90
LS4 L	-1.93	-2.03	-2.33	-5.45	-4.88
LS4 D	-0.83	-1.55	-1.33	-2.43	-0.70
LS5 L	-1.20	-4.18	-4.20	-3.90	-5.28
LS5 D	-2.40	-2.58	-3.13	-2.88	-5.75
LS6 L	-6.40	-4.35	-2.58	-4.05	-2.25
LS6 D	-3.43	-4.53	-4.30	-3.75	-6.25
LS7 L	2.73	0.95	-1.13	0.60	4.30
LS7 D	-1.43	0.20	-1.08	-1.13	-3.38
LS8 L	-3.40	-6.30	-3.28	-2.43	-4.25
LS8 D	-7.53	-6.10	-6.40	-6.25	-7.60
LS9 L	-3.03	-0.65	-2.05	-2.00	-4.28
LS9 D	-1.83	-2.53	-2.63	-1.10	-1.00
LS10 L	-2.08	2.63	1.13	3.10	3.90
LS10 D	-2.80	-4.25	-3.90	-6.80	-3.08
GRM L	-3.04	-2.84	-2.25	-2.12	-1.84
GRM D	-3.04	-3.37	-3.41	-3.45	-3.91

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c.1 Visual and proprioceptive inputs on spatial orientation in the pitch dimension.